expect to obtain relatively high power with this transition, since lasing is effected at relatively low energy levels.

The upper $2p_5$ state is connected with only one of the 1s states, and should therefore have a lower probability of spontaneous decay compared with the other 2p states. The lower $3d_5$ state is coupled by strong transitions with the $2p_6$ and $2p_7$ levels, and also with the ground state. The undesirable reabsorption accompanying the strong coupling between the $3d_5$ level and the ground state can be reduced by decreasing the diameter of the discharge tube to a reasonable size.

Emission of a 75.5778 μ wavelength was effected by us in the mixtures He + Xe (100:1) at optimal pressure $p_{Xe} = 3.5 \times 10^{-2}$ mm Hg and Kr + Xe (3:1) at $p_{Xe} = (1.5 - 2) \times 10^{-2}$ mm Hg. A generator was used with high-frequency discharge and with internal confocal silvered mirrors with reflection coefficients 100 and 95%; the substrates were of crystalline quartz. The length of the discharge quartz tube was 1.80 m and the inside diameter was 6 mm.

The authors are deeply grateful to T. M. Livshitz for supplying the far-infrared receiver developed by him.

[1] A. M. Prokhorov, JETP 34, 1656 (1958), Soviet Phys. JETP 7, 1139 (1958).
[2] T. H. Maimen, Nature 187, 493 (1960).
[3] A. Javan, Phys. Rev. Lett. 3, 87 (1959).
[4] Faust, McFarlane, Patel, and Garret, Phys. Rev. 133, A1476 (1964); Proc. I EEE 52, 318 (1964); Appl. Phys. 4, 18 (1964).
[5] W. R. Bennett, Jr., Applied Optics. Suppl. No. 1 on Optical Masers, 1962, pp. 24-62.

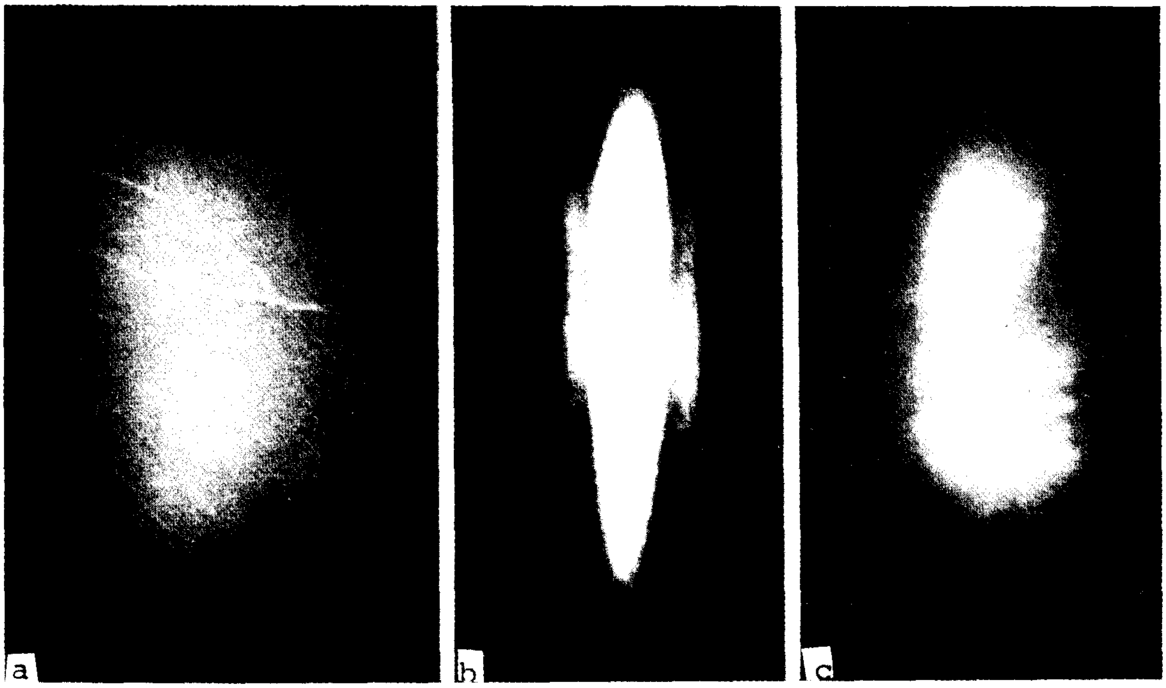
FREQUENCY DEPENDENCE OF THE THRESHOLD OF OPTICAL BREAKDOWN IN AIR

S. A. Akhmanov, A. I. Kovrigin, M. M. Strukov, and R. V. Khokhlov
Moscow State University
Original submitted 20 February 1965

The breakdown of a gas in the focus of an intense light wave, reported in[1-4], can be related either to cascade multiplication of free electrons (a theory of this process was presented in[5]) or to multiphoton processes (cf.[6, 7]). Although the dependence of the threshold light-field intensity E^{thr} on the pressure, measured in[2, 3], can be satisfactorily described by the theory of cascade breakdown, the influence of multiphoton processes cannot be regarded as excluded. This was pointed out, in particular, by Nelson et al.[8], who measured the absorption in air near the breakdown threshold and interpreted their results on the basis of multiphoton-process concepts. It should be noted that in all the foregoing investigations the breadkown was studied at a single wavelength, $\lambda \gtrsim 0.7\ \mu$. It seems to us that this question can be clarified to a definite degree by measuring the frequency dependence of the threshold electric field intensity. Indeed, according to [5] the threshold intensity E^{thr} increases with frequency in cascade multiplication of free electrons. On the other hand, according to [7] the probability of ionization in a strong light field is proportional to $\exp(-I_0/h\omega)$, where I_0 is the effective ionization potential. Consequently, E^{thr} decreases with increasing frequency in the case of photoionization. However, when different lasers are used in such measurements (breakdown was observed so far only in the fields of a ruby or neodymium-glass laser) systematic errors arise, due to the different beam spreads, different focusing conditions, etc. The relatively slight frequency difference (by merely a factor 1.5) consequently makes such measurements difficult. We have therefore investigated optical breakdown with the emission of a neodymium-glass laser and its second harmonic ($\lambda_1 = 1.06\mu$, $\lambda_2 \approx 0.53\mu$). Under certain conditions it is possible to obtain light beams with nearly equal geometry and the ratio of the pulse durations can be controlled with sufficient reliability.

Frequency doubling of a Q-switched neodymium-laser with Q-modulation was effected with a KDP (potassium dihydrogen phosphate) crystal. The ratio of the beam spreads at the fundamental (α_1) to that at the second harmonic (α_2) depends on the ratio of the coherent length of nonlinear interaction $L_c = 2\pi/K\alpha_1$ (where K is a coefficient determined by the dispersion properties of the crystal, cf. e. g.[9-11]) to the crystal length ℓ. $\alpha_2 < \alpha_1$ when $\ell > L_c$, and the harmonic consists of a set of bands whose intensity varies like $[(\sin\alpha)/\alpha]^2$, whereas $\alpha_2 \simeq \alpha_1$ when $L \leq L_c$.

The figure shows photographs of the transverse structure of the fundamental radiation and of the second harmonic for the two indicated cases. In our experiments $\ell \gtrsim L_c$ with ℓ = 2 cm and $\alpha_1 \gtrsim 10'$.



Photographs of the transverse structure of the fundamental and second-harmonic beams: a - fundamental radiation, b - second harmonic for $\ell > L_c$, c - second harmonic for $\ell < L_c$.

The threshold measurement scheme was conventional. The laser emission or its second harmonic was focused in air with planoconvex lenses (thereby increasing the spherical aberration appreciably) with focal distances f = 4 cm and f = 6 cm. The radiation energy $W_{1,2}$ was measured with a calorimeter so placed that its entrance pupil exceeded the cross section of the beam emerging from the focus.

The ratio of the squares of the threshold-field intensities E_1^{thr} and E_2^{thr} is

$$[E_1^{thr}/E_2^{thr}]^2 = W_1^{thr}\sigma_2 t_2/W_2^{thr}\sigma_1 t_1 \qquad (1)$$

where $W_{1,2}^{thr}$ are the threshold energies measured with the calorimeter (these values correspond to the appearance of the spark and are about 20% accurate), $\sigma_{1,2}$ are the areas of the focal spot at the fundamental and second harmonic, and $t_{1,2}$ are the durations of the corresponding pulses.

Typical values of the experimentally determined ratios $\xi = W_1^{thr}/W_2^{thr}$ and average values obtained for 10 measurements are:

4 cm lens:

$\xi = 0.58 \quad 0.62 \quad 0.70 \quad 0.49 \quad 0.6 \qquad \bar{\xi} = 0.6 \quad \frac{\sqrt{\overline{\Delta\xi^2}}}{\xi} = 25\% - 30\%$

6 cm lens:

$\xi = 0.6 \quad 0.58 \quad 0.64 \quad 0.6 \quad 0.66 \qquad \bar{\xi} = 0.63 \quad \frac{\sqrt{\overline{\Delta\xi^2}}}{\xi} = 25\% - 30\%$

In our experiments the ratio t_2/t_1 was usually $(\overline{t_2/t_1}) \gtrsim 0.75$ (the second-harmonic pulse is the square of the fundamental pulse). By virtue of the foregoing, the ratio σ_2/σ_1 is always smaller than or equal to unity (see also the figure; in our experiments values of σ_2/σ_2 ranging from unity to 0.65 - 0.7 were possible). The diameter $D_{1,2}$ of the focal spot was estimated by us to be $D = \alpha f$. Using this estimate, typical values of the breakdown field are $E_1^{thr} \approx 5 \times 10^6$ V/cm ($D_1 \approx 2 \times 10^{-2}$ cm, $t_1 \approx 40 \times 10^{-9}$ sec, $W_1^{thr} \approx 0.3$ J).

The results show, in our opinion, that the dominating breakdown mechanism at wavelengths longer than 0.53 μ is cascade multiplication of free electrons. Indeed, if the free electrons multiply like $N = N_0 \exp(t/\theta)$, then the breakdown corresponds to a definite value of the exponent t_i/θ_i (i = 1, 2) attained within the time of the light pulse. The electron-cascade time constant θ_i, assuming the multiplication to be purely classical, is according to [5] $\theta_i \sim kI_1\omega_i^2/E_i^2$, where I_1 is the energy needed to ionize the atom, and k is a coefficient. Thus, the value of $t_i E_i^2/\omega_i^2$ is fixed at the instant of the breakdown, and consequently

$$\eta = \frac{W_1^{thr}}{W_2^{thr}} \cdot \frac{\sigma_2}{\sigma_1} = \frac{\omega_1^2}{\omega_1^2} \qquad (2)$$

by virtue of the foregoing, $\eta_{exp} \approx 0.4 - 0.5$, and this exceeds the value $\eta_{theor} = 0.25$ given by (2). This discrepancy exceeds the limits of experimental error and can be attributed either to quantum effects when the free electrons acquire energy, or to multiphoton absorption. That the latter makes a definite contribution is evidenced apparently by the results of our measurements of the light absorption at the focus of the lens during the pre-breakdown stage, which amounted approximately to 10% and 20% at 1.06 and 0.53 μ, respectively.

We note in conclusion that the use of harmonic generators permits a study of the breakdown effect in biharmonic fields. Preliminary experiments have shown that a joint action of the fundamental and second-harmonic fields takes place in air. It is of interest to study the frequency dependence of breakdown in condensed media. We propose to publish elesewhere some results of a study of breakdown in liquids.

We are grateful to G. A. Askar'yan and F. B. Bunkin for useful discussions and to N. K. Kulakova for help with the measurements.

[1] E. K. Dammon and R. G. Tomlinson, Appl. Optics 2, 546 (1963).

[2] R. G. Meyerhand and A. F. Haught, Phys. Rev. Lett. 11, 401 (1963).

[3] R. Mink, J. Appl. Phys. 35, 252 (1964).

[4] Mandel'shtam, Pashinin, Prokindeev, Prokhorov, and Sukhodrev, JETP 47, 2003 (1964), Soviet Phys. JETP 20, 1344 (1965).

[5] Ya. B. Zel'dovich and Yu. P. Raizer, JETP 47, 1150 (1964), Soviet Phys. JETP 20, 772 (1965).

[6] F. V. Bunkin and A. M. Prokhorov, JETP 46, 1090 (1964), Soviet Phys. JETP 19, 739 (1964).

[7] L. V. Keldysh, JETP 47, 1945 (1964), Soviet Phys. JETP 20, 1307 (1965).

[8] Nelson, Veyrie, Berry, and Durand, Phys. Lett. 13, 226 (1964).

[9] D. Kleinman, Phys. Rev. 128, 1761 (1962).

[10] S. A. Akhmanov and R. V. Khokhlov, Problemy nelineinoi optiki (Problems of Nonlinear Optics), M., 1964.

[11] Akhmanov, Kovrigin, Chunaev, and Khokhlov, JETP 45, 1336 (1963), Soviet Phys. JETP 18, 919 (1964).

MAGNETIC MOMENTS OF BARYONS AND SU(6) SYMMETRY

A. I. Akhiezer and M. P. Rekalo
Physico-technical Institute, Academy of Sciences, Ukrainian S.S.R.
Original submitted 25 February 1965.

The results of Sakita[1] and of Pais et al.[2] do not take account of moderately strong interaction violating SU(6) symmetry and playing an important role in mass formulas. It is therefore of interest to ascertain the influence of moderately strong interaction on the relations between the magnetic moments of baryons. We shall show that even when account is taken of moderately strong interaction the relation between $\mu(p)$ and $\mu(n)$ is conserved.